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# The Development of the Generalized Spallation Model

Chase Juneau, Leslie Kerby

Nov. 1<sup>st</sup>, 2017

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# Topics

- Background
- Introduction
- Work Performed
- Results
- Conclusion
- Future Work

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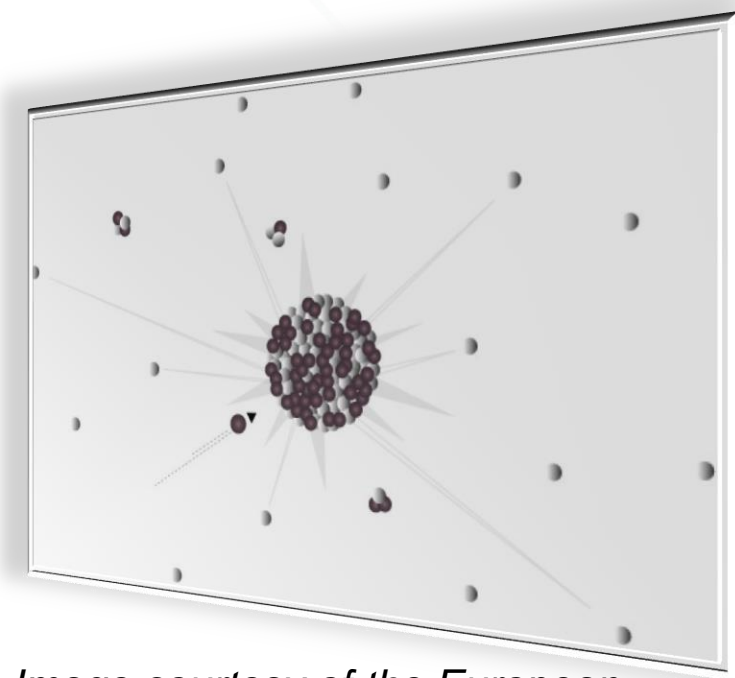
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# Background – Event Generators

- CEM
  - “Cascade Exciton Model”
  - $100 \text{ MeV} \leq E \leq 4.5 \text{ GeV}$
  
- LAQGSM
  - “Los Alamos Quark-Gluon String Model”
  - $4.5 \text{ GeV}/A \leq E \leq 1 \text{ TeV}/A$

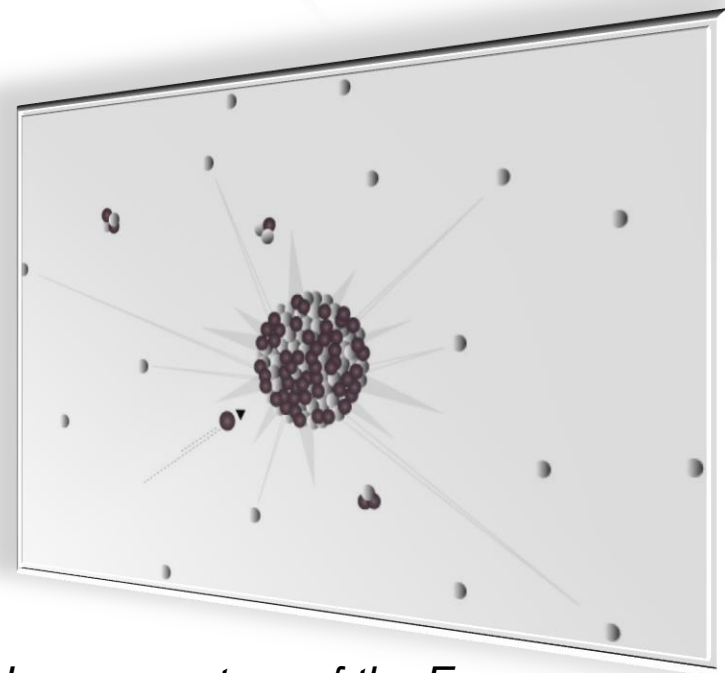


*Image courtesy of the European Spallation Source (click [here](#) for more information).*

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# Background - Physics

- *The reaction is broken into stages*
  - *Precompound stage*
    - *IntraNuclear Cascade (INC)*
    - *Coalescence*
    - *Preequilibrium*
  - *Compound stage*
    - *Evaporation*
    - *Fission*
  - *Fermi breakup*

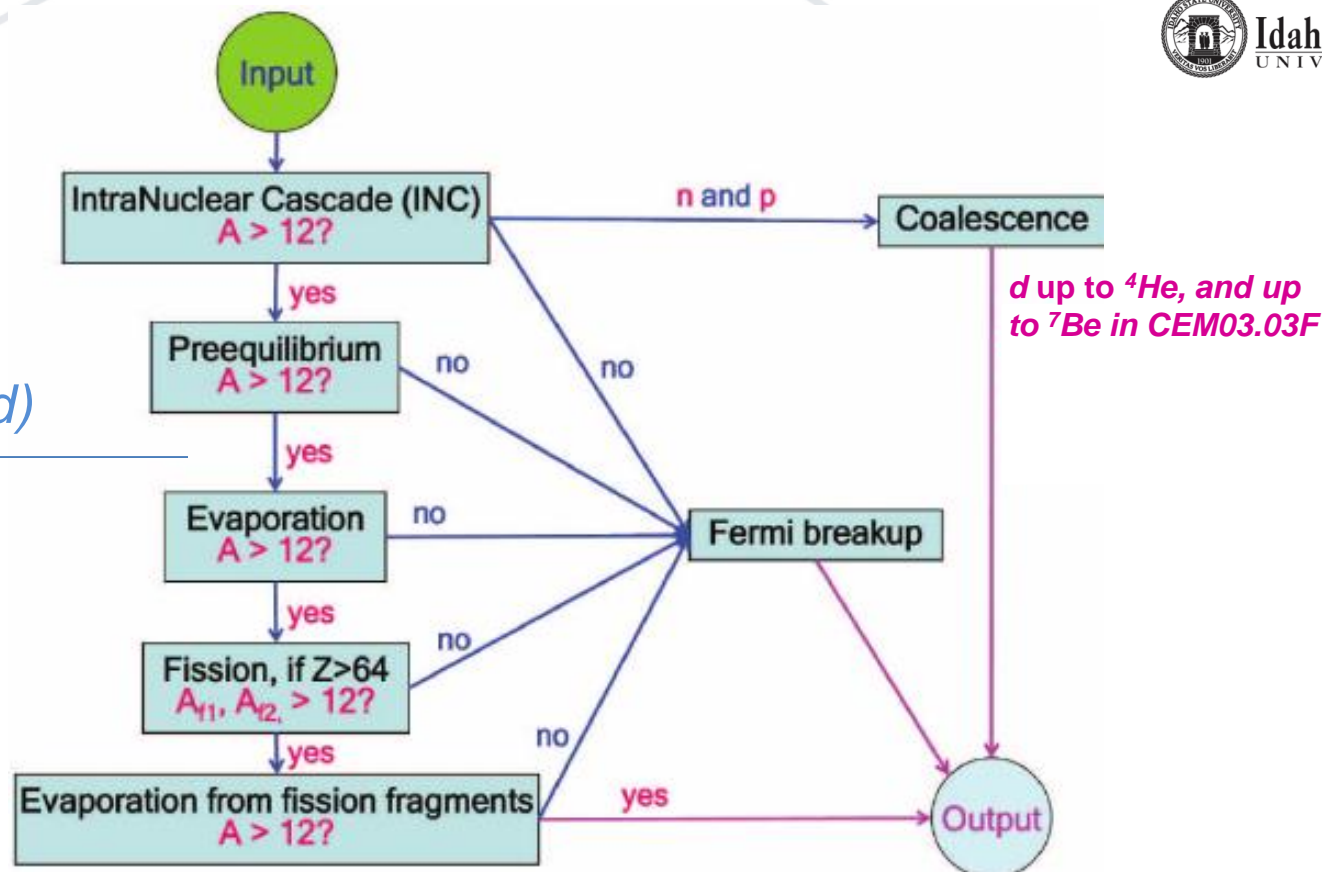


*Image courtesy of the European Spallation Source (click [here](#) for more information).*

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# Background - Physics



*Flow chart of the calculations undertaken by the spallation models used in MCNP.*

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# Introduction

- Motivation is to investigate the deprecation of LAQGSM
  - GSM will be as comprehensive as CEM and LAQGSM combined
- GSM was built on the code of the CEM and LAQGSM event generators
  - GSM is an expansion of CEM

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# Introduction

- Can be used in place of CEM and LAQGSM within MCNP



- Benefits include
  - Generally improved predictions
  - Less legacy code

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```

COMMON/NCASCA/NCAS, NCPRI
COMMON /MEMORY/ PME (9, 5999), IME (5, 5999)
COMMON/INTCEN/IPO, INT1 (300), INT2 (5999), INT3 (5999),
*          INT4 (100000), IJPA, IST, JST, NRST
COMMON/TAUIJ/  TAU, TPTS, TYPS, TYTS, TYYS, TIJ4 (100000)
COMMON/NUCOLL/ NUCOLL, MVCOLL (5999)
COMMON/ACTIV/MPA (300), MYP (5999), MYT (5999), MYY (5999)
COMMON/TLIMIT/TLIMIT
COMMON/ACTIM/TINT
COMMON/IPAUL/IP
COMMON/INTCC/INTCC
COMMON/IACT/  IACT/CVALON/  IVALON
COMMON/CSLID/CLIDER (5999)
DIMENSION RIJ (3), VIJ (3), NYY (5999)
TAU=-.1
IF (MV.LE.1)                                RETURN
IF (IP.EQ.0.OR.IPO.EQ.1)                    GO TO 15
DO 8 I=1, MV
8 NYY (I) =MYI (I)
DO 13 I=2, MV
IF (IME (2, I) .NE.0)                      GO TO 13
CLIDI=CLIDER (I)
EI=PME (8, I) +PME (9, I)
INU=0
IF ( IME (2, I) .EQ.0.AND.IME (3, I) .EQ.0.AND.IME (4, I) .EQ.1.
*AND.IME (5, I) .EQ.0)  INU=1
JM=I-1
DO 12 J=1, JM
IF (IME (2, J) .NE.0)                      GO TO 12
IF (MVCOLL (I) .EQ.MVCOLL (J) )           GO TO 12
IF (MYI (I) .EQ.1)                         GO TO 9
IF (MYI (J) .EQ.1)                         GO TO 9
GO TO 12
9 JNU=0

```

*A small segment of LAQGSM code.*

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# Introduction

- GSM offers predictions for particle
  - Production cross sections
  - Multiplicities
  - Kinetic energies
  - etc.
- Where can GSM be used?
  - Recall that GSM requires large kinetic energies

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# Introduction - Applications

- Accelerators

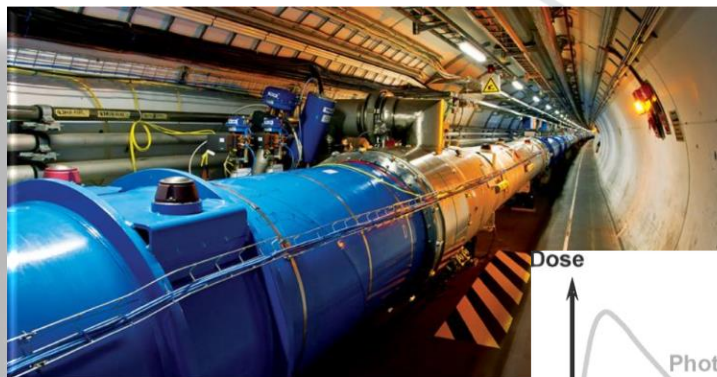


Image courtesy of CERN (click [here](#) for more information).

- Medical



Image courtesy of NASA (click [here](#) for more information).

- Space

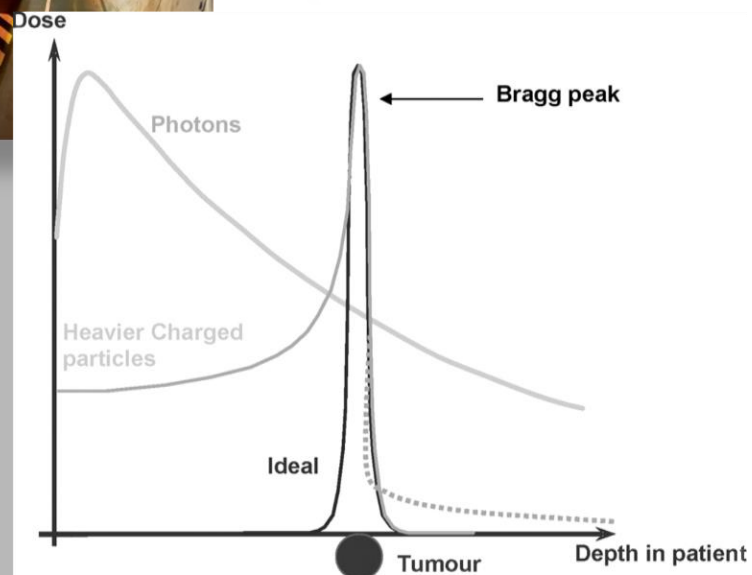


Image courtesy of Pijls-Johannesma, Madelon, *et al.*, "Do we have enough evidence to implement particle therapy as standard treatment in lung cancer? A systematic literature review." *The oncologist* 15.1 (2010): 93-103.

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# Work Performed

- Added LAQGSM physics to GSM
  - Namely the time dependent cascade model
- Data analysis
- Some Verification and Validation (V&V)
  - Namely Software Quality Assurance (SQA)

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# Results

- Removed ~30% of LAQGSM code

- *12,000 lines!*

- More user options and  
a more robust output

- Generally improved  
predictions

```
COMMON/NCASCA/NCAS, NCPRI
COMMON /MEMORY/ PME (9,5999), IME (5,5999)
COMMON/INTCEN/IPO, INT1 (300), INT2 (5999), INT3 (5999),
*      INT4 (100000), IJPA, IST, JST, NRST
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COMMON/NUCOLL/ NUCOLL, MVCOLL (5999)
COMMON/ACTIV/MPA (300), MYP (5999), MYT (5999), MYX (5999)
COMMON/TLIMIT/TLIMIT
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JM=I-1
DO 12 J=1, JM
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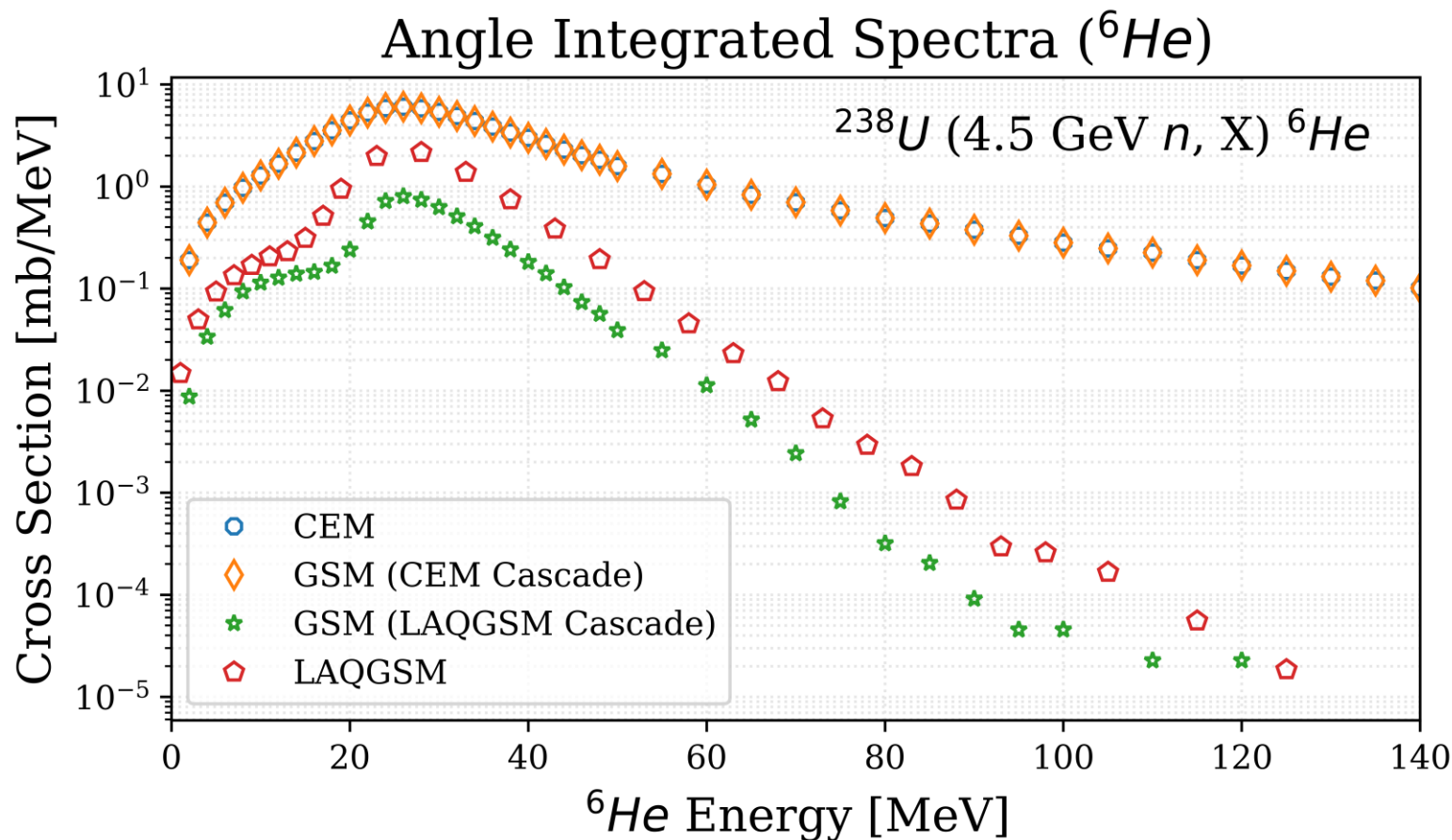
# Results - Threshold

- GSM uses the cascade model from the CEM event generator below the threshold energy for incident nucleons, pions, and photons
- GSM uses the cascade model of the LAQGSM event generator otherwise
- How do the cascade models compare?

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# Results - Threshold

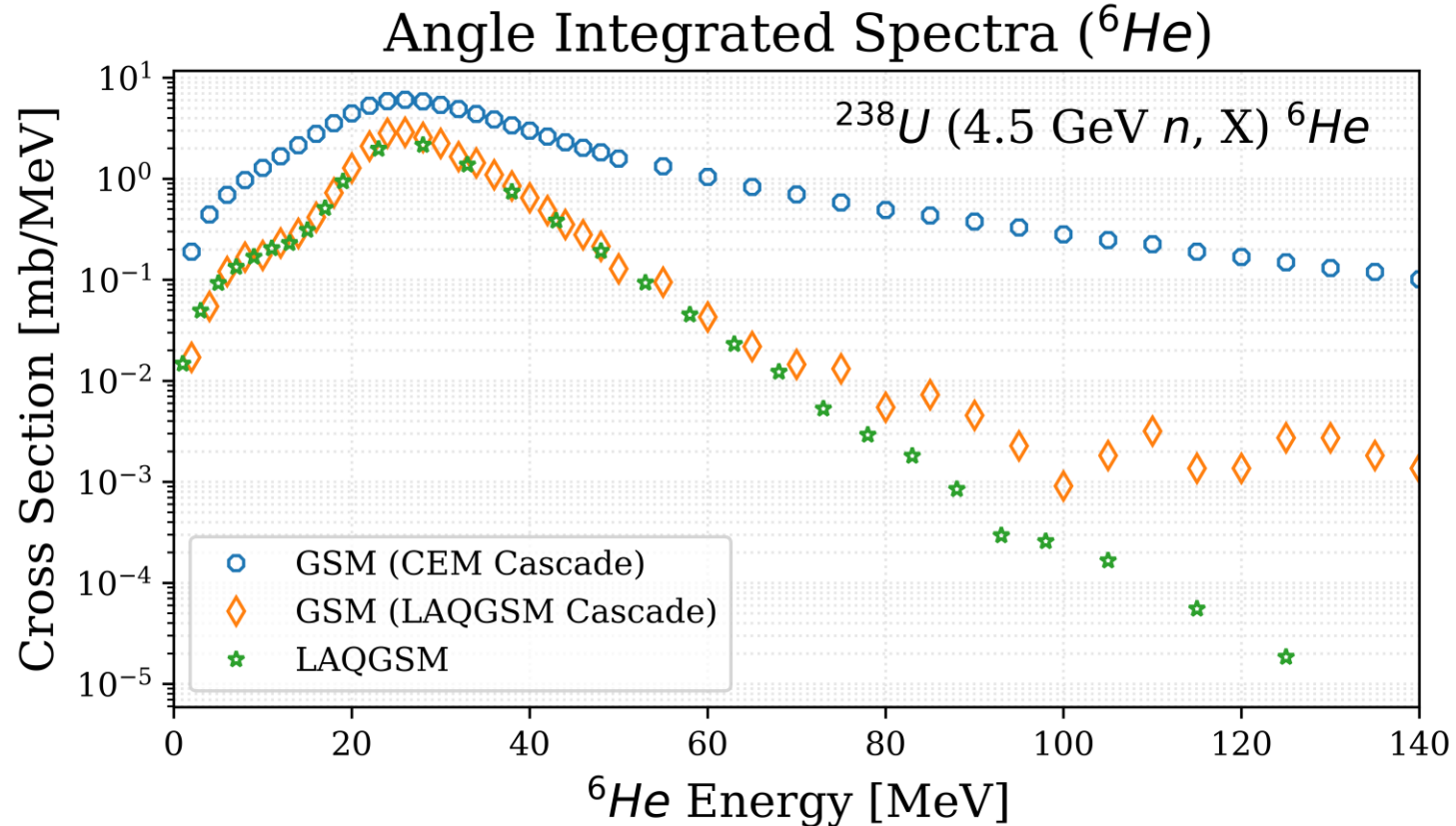


${}^6\text{He}$  production cross section from 4.5 GeV neutrons striking  ${}^{238}\text{U}$ . No experimental data available.

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# Results – High Energy Upgrades

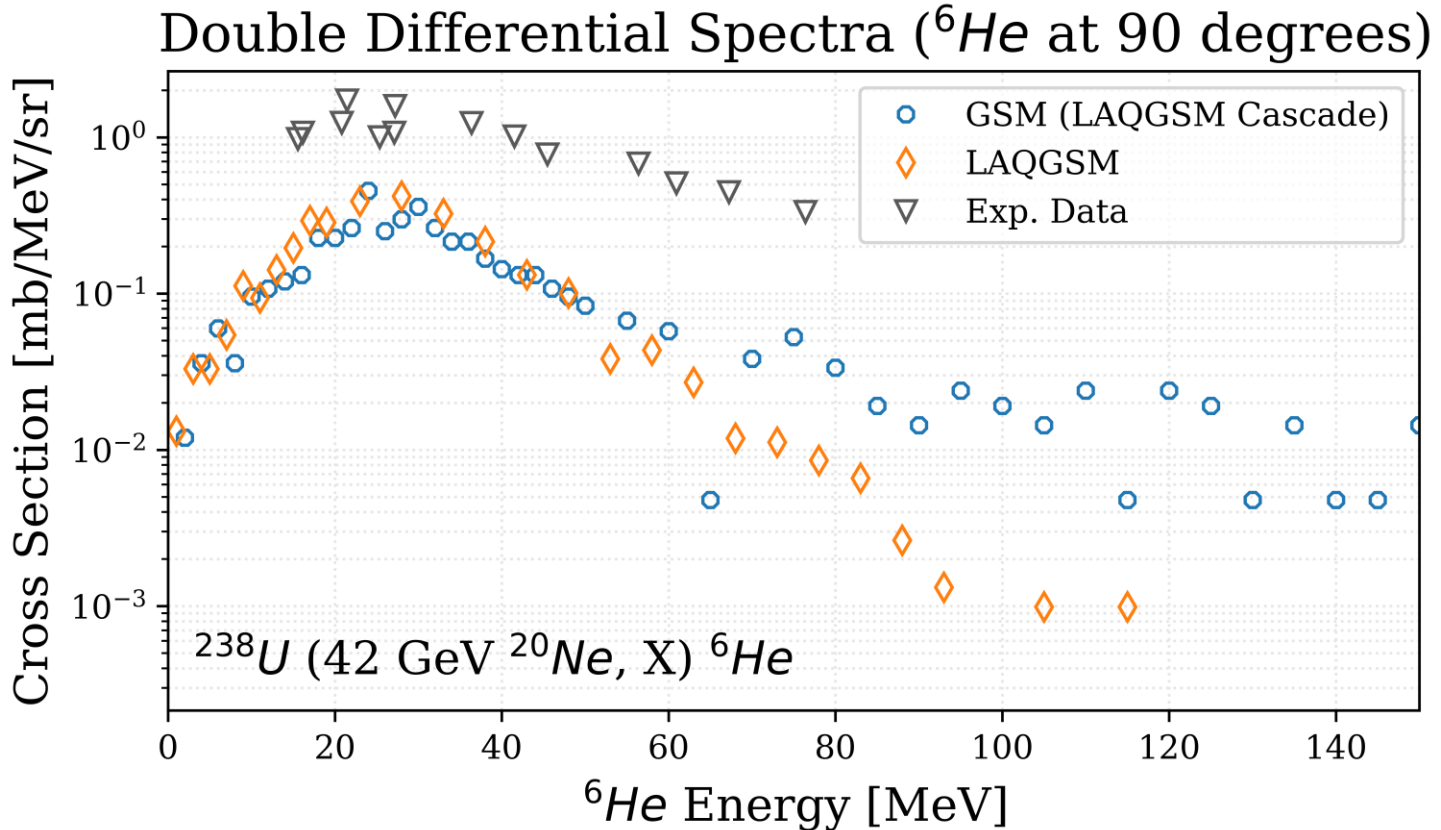


${}^6\text{He}$  production cross section from 4.5 GeV neutrons striking  ${}^{238}\text{U}$ . No experimental data available.

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# Results – High Energy Upgrades



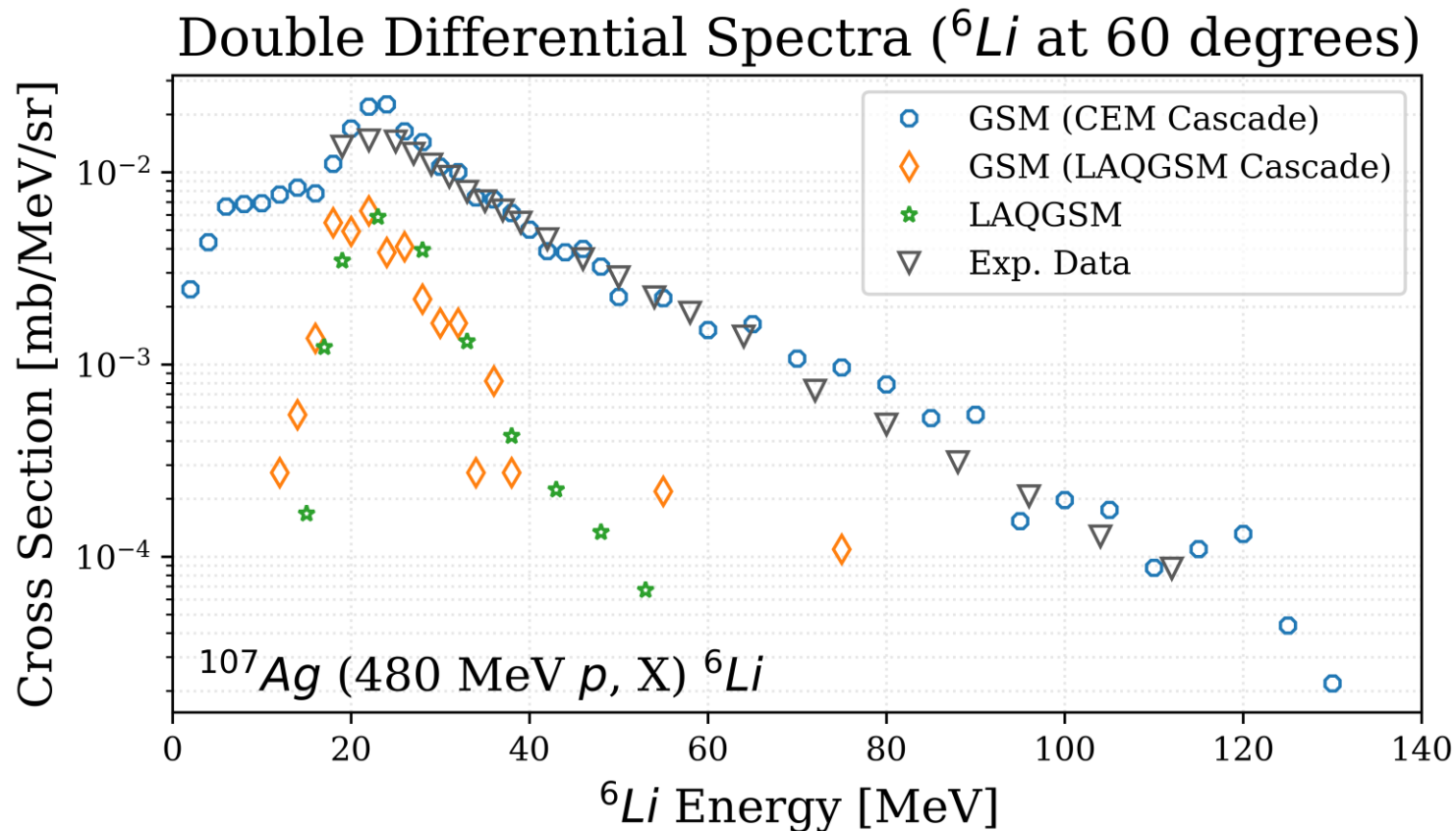
${}^6\text{He}$  production cross section from 2.1 GeV/A  ${}^{20}\text{Ne}$  striking  ${}^{238}\text{U}$ . Data from Gossett *et al.*, “Central Collisions of Relativistic Heavy Ions.”

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# Results – High Energy Upgrades



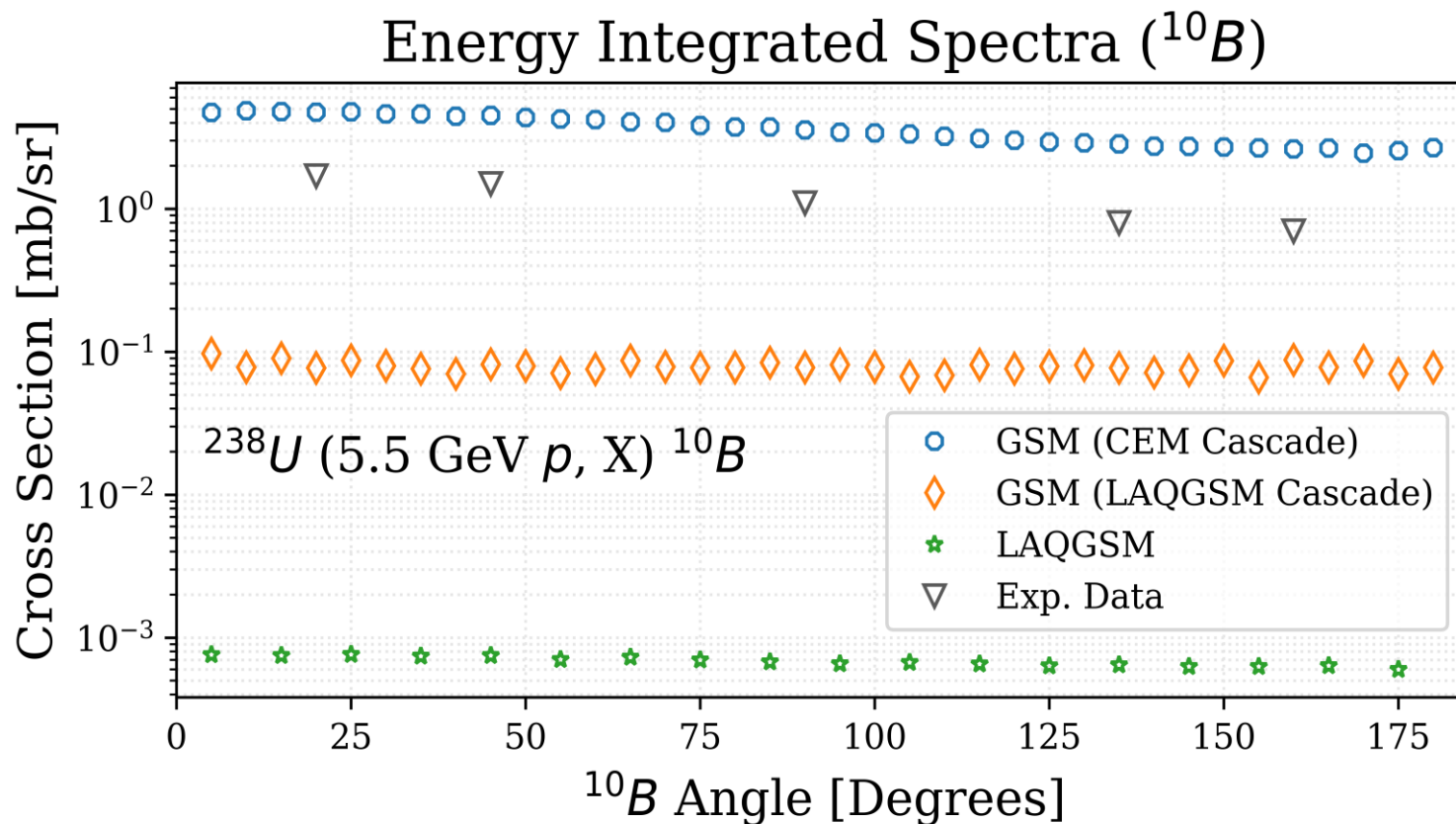
${}^6\text{Li}$  production cross section from 480 MeV protons striking  ${}^{107}\text{Ag}$ . Data from Green et al., "Inclusive Production of Isotopically Resolved Li through Mg Fragments by 480 MeV  $p + \text{Ag}$  Reactions."

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# Results - Integrated Spectra

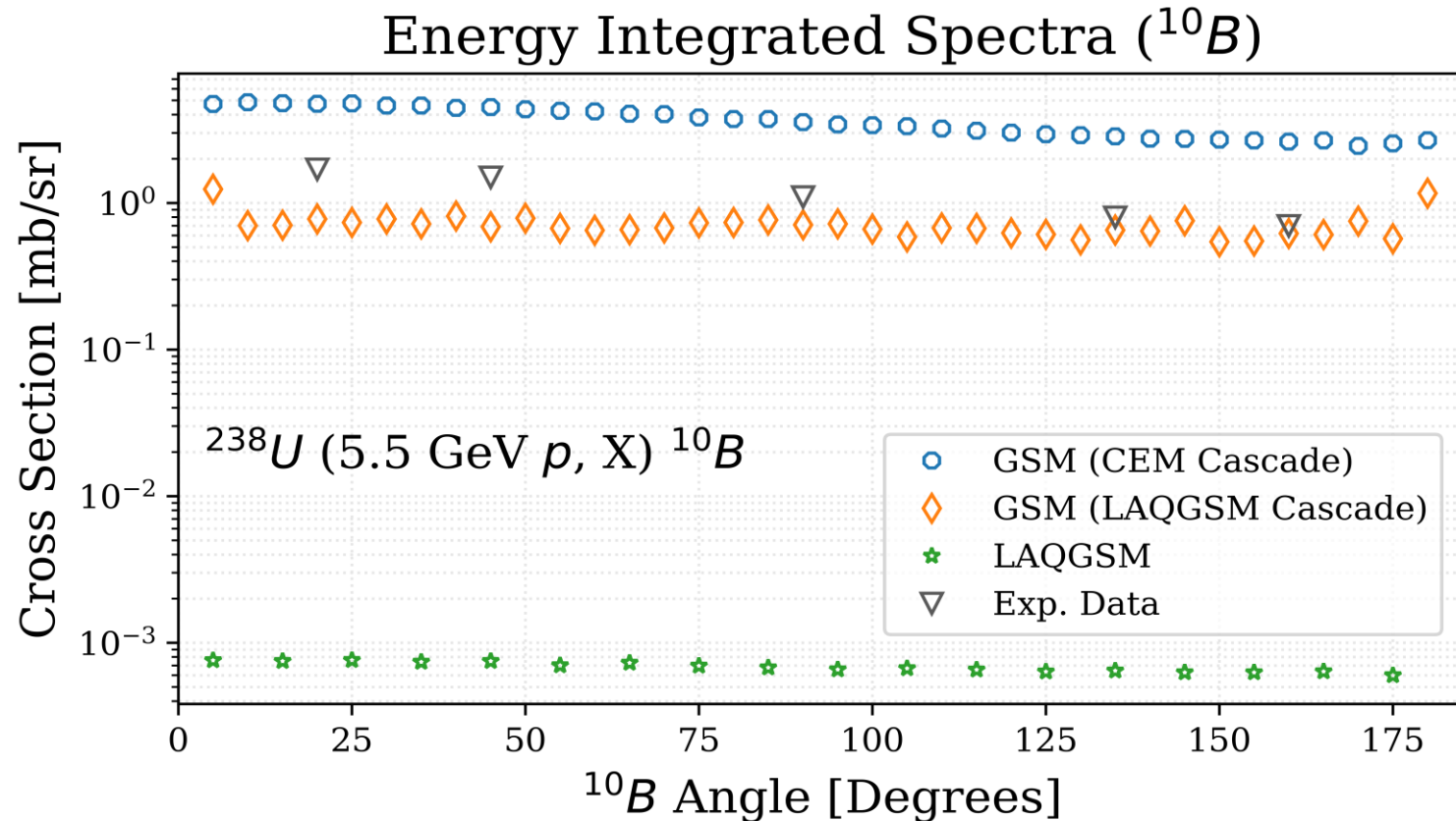


$^{10}\text{B}$  production cross section from 5.5 GeV protons striking  $^{238}\text{U}$ . Data from Ponzaker, et al., "Fragment Production in the Interaction of 5.5-GeV Protons with Uranium."

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# Results - Integrated Spectra



$^{10}\text{B}$  production cross section from 5.5 GeV protons striking  $^{238}\text{U}$ . Data from Ponzaker, et al., "Fragment Production in the Interaction of 5.5-GeV Protons with Uranium."

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# Conclusion/Summary

- GSM predictions are similar to those of LAQGSM, with some generally improved predictions
  - More improvements to be completed
- Removed legacy code (~30%)
- Further V&V is necessary

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# Topics

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# Future Work

- Optimization
- V&V
- API/Driver
- Improvements
  - Better predictions
  - Modernization



*Image courtesy of Marketing91 from Hitesh Bhasin's blog (click [here](#) for more information).*



*Image courtesy of Retriever Media Informatie (click [here](#) for more information).*

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***Thank you!***



**Comments?**

**Questions?**

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